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APPLICATION OF STRUCTURED PLANT OILS IN SELECTED FOOD PRODUCTS

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ABSTRACT

The joint statutory recommendations developed by the UN Food and Agriculture Organization (FAO) and the World Health Organization (WHO), the greater consumer awareness, and environmental considerations confirm the need to reduce the consumption of saturated fatty acids in the human diet. This has contributed to the development of innovative methods for replacement of saturated fats in food products. Oleogels obtained with various methods are such an alternative. Therefore, the study was focused on the analysis of the current applications of oleogels in selected food products and elucidation of the mechanisms of oleogel formation. As indicated by many researchers, oleogels (structured oils) can replace *trans* and saturated fats in food products and can be used in the production of spreads as well as bakery, confectionery, and dairy products. However, there are still many challenges and technological problems preventing commercial application of oleogels in the industry. It is also important to develop oleogels with higher physical and antioxidant stability, which will be used in a wide range of food products manufactured in varying production conditions and give the final products the desired sensory properties. Nevertheless, given its nutritional and environmental values, oleogelation has great potential for future industrial use.

Introduction

The quantity and quality of consumed fat play a special role in the development of human metabolic and lifestyle diseases. The joint statutory recommendations developed by the UN Food and Agriculture Organization (FAO) and the World Health Organization (WHO) confirm the need to reduce the consumption of saturated fatty acids in the human diet, in particular lauric, myristic, and palmitic acids. The guidelines specify that 30% of the daily energy intake with food should derive from fat with the upper limit of saturated fat intake established at < 10%. Additionally, the greater consumer health-related awareness and the environmental considerations associated with sustainable practices in palm oil production recommend limitation of the consumption of saturated fatty acid-rich products and replacement there of with polyunsaturated fatty acid-rich foods (Nishida et al., 2004; FDA, 2015; WHO, 2019).

Replacement of fat in food products (without a quantitative change in the total fat intake) is difficult, as the important functions of fat in products consist in determination of nutritional, physical, and sensory properties. In physiological terms, fat is the most concentrated source of energy in the human diet. It provides essential unsaturated fatty acids (EFAs) and is a carrier of many biologically active substances, including fat-soluble vitamins. In technological terms, fats determine the physical properties of food (viscosity, melting characteristics, crystalline state, spreadability) and behavior during processing (thermal stability, viscosity, aeration capacity) and storage (migration and separation of fat, oxidation, water activity). The sensory functions of fat are primarily involved in the appropriate taste and smell of food, owing to the presence of flavor and aroma compounds dissolved in fat (Puşcaş et al., 2020). The basic components of all fats are saturated (SFA) and unsaturated fatty acids (Tab. 1).

Table 1.
Composition of fatty acids in vegetable oils expressed in $g \cdot 100g^{-1}$ of fatty acids (Gutiérrez-Luna et al., 2022)

Type of fat	**SFA**	**MUFA**	**PUFA**
Sunflower oil	12.8-12.9	22.4-27.2	58.8-66.0
HO sunflower oil	6.0-9.9	80.0-85.0	3.8-9.0
Grape seed oil	6.7-10.5	14.3-18.4	65.4-74.7
Rapeseed oil	7.4	63.3	28.1: oleic (C 18:1) – 62%
Cotton seed oil	25.9-28.2	17.8-19.66	51.9-53.4
Camellia oil	10.78	78.98	9.61
Soybean oil	15.6-16.7	20.4-24.8	57.7 – 61.8: linoleic (C 18:2) – 60%
Olive oil	13.8-15.3	73.0-73.8	10.0: oleic (C 18:1) – 75%
Hazelnut oil	7.0-7.8.0	75.0-83.1	9.0-13.0
Flaxseed oil	9.0-12.7	17.8-18.4	51.9 – 67.8: linolenic (C 18:3) – 59%
Palm oil	49.3	37.0	9.3
Cocoa butter	57.0-62.9	29.0-34.1	5.0
Shea butter	46.5	48.0	5.4
Palm stearin	50.0-67.11	26.6-35.0	5.87

Depending on the number of double bonds in the carbon chain, unsaturated fatty acids are divided into monounsaturated (monoenic - MUFA) and polyunsaturated (polyenic - PUFA) fatty acids. For proper functioning of the organism, essential fatty acids (EFAs) are the most important unsaturated acids. They are not produced in the human organism but are indispensable for its proper development and functioning. Polyenic fatty acids (PUFA) contain from 2 to 6 double bonds in the *cis* configuration. They are usually divided into the following groups: n-9, n-6 (linoleic acid, gamma-linolenic, and arachidonic acids), and n-3 (alpha-linolenic acid). The number indicates the location of the first double bond from the end of the carbon chain. Vegetable fats (oils), which are obtained from seeds (soybean, rapeseed, sunflower, peanut, and corn oils) or fruits of oil plants (olive and palm oils), are the basic source of EFAs. Other oil raw materials are cotton, flax, safflower, sesame, poppy, Abyssinian cabbage, oil radish, coconut, and oil palm (kernel) seeds (Krajewska et al., 2016; Gutiérrez-Luna et al., 2022).

Natural solid or modified fats are used in food production most frequently. The most common method is hydrogenation, i.e. a process of saturation of some or all double bonds in fatty acids with hydrogen, which results in the formation of saturated solid fats characterized by better oxidative stability and plasticity. Although this process is technologically advantageous, it induces considerable changes in the nutritional value of fats at the expense of polyunsaturated acids (the content of saturated and monounsaturated acids increases). The formation of *trans* fatty acids, which have a negative effect on human health, is an especially unfavorable phenomenon. The amount of isomers formed depends on the technological parameters of the process (temperature, hydrogen pressure, type of catalysts) and the type of fat subjected to hydrogenation. Hence, there is a need for production of healthier, *trans*-fat free, stable, and solid fats that retain their structure at ambient temperatures and have a longer shelf life (Puşcaş et al., 2020). Therefore, the present study was focused on analysis of oleogels (structured vegetable oils) as an alternative to saturated fats and *trans* fatty acid isomers in food, which can yield products with desirable nutritional value and functional properties.

Methods and conditions for production of oleogels

One of the promising alternatives for hardening unsaturated fatty acid-rich oils is oleogelation, i.e. a method of structuring plant oils *via* oil entrapment in three-dimensional networks, which does not change their chemical composition, and the resulting structure has the properties of a solid. The formation of a gel structure is facilitated by the use structuring substances with viscous and elastic consistency. This process contributes to reduction in the consumption of saturated fatty acids and *trans* isomers and to an increase in the nutritional quality of products through the application of oils that contain essential fatty acids, phytosterols, flavonoids, and other functional ingredients. The gel structure generated with the involvement of structuring substances and large amounts of vegetable oils (usually approximately 90%) offers new opportunities for the use of liquid fats in the food industry. The method yields products that are able to meet consumer expectations and retain their flavor qualities.

Oleogels produced with this method can be used in various food products to replace solid fats or reduce the amounts of saturated fats, e.g. in dairy products, ice cream, bakery products, breakfast products, chocolate-based products, and meat products or for production of commercial fats. In addition to their basic benefits, i.e. replacement of fats, oleogels can increase the availability of bioactive compounds present in vegetable oils (Puşcaş et al., 2020; Banaś and Harasym, 2021; Moriano and Alamprese, 2017).

Structuring substances are divided into two groups: low and high molecular weight oleogelators (LMOGs and HMOGs) (Tab. 2). LMOGs are low molecular weight compounds with the capability of independent formation of the crystal network of the emerging oleogel, e.g. fatty acids, sugar alcohols, waxes, wax esters, and mono- and diglycerides. The other group is represented by such high-molecular substances as proteins and polysaccharides, which have the ability to bind oils and form a three-dimensional network via hydrogen bonds. Oleogels prepared with the use of polysaccharides exhibit viscoelastic properties, which are strongly influenced by their molecular weight and concentration. The structuring substances are approved as GRAS (*Generally Recognized as Safe*) or food additives. As natural additives, polysaccharides are the most promising group of such substances used for production of oleogels most frequently. The functionality of polysaccharides is associated with their molecular structure, differences in the molecular structure, and origin (Banaś and Harasym, 2021; Davidovich-Pinhas, 2019).

The following factors exert an impact on the physical properties of oleogels:
– type of the structuring substance,
– solvent phase,
– chemical composition,
– percentage proportions of components,
– physical properties (density),
– food processing methods (high pressure, temperature),
– preparation and conditions of the process,
– preparation of the sample (mixing time and speed, ultrasonic homogenization, heating temperature, cooling rate, gel binding, storage temperature)

Table 2.
Types of structuring substances used for formation of oleogels (Banaś and Harasym, 2021)

Oleogels	
LMOGs low molecular weight structuring substances	HMOGs high molecular weight structuring substances
- simple sugars (e.g. trehalose, sucrose, mannose) - glycosides (raspberry glycoside ketone) - sugar alcohols (e.g. xylitol, sorbitol, mannitol) - waxes - fatty acids - carbamates - lecithins - ceramides - monoacylglycerols. diacylglycerols. triacylglycerols - n-alkanes - mixtures of γ-oryzanol and phytosterols	- proteins (e.g. β-lactoglobulin) - some polymers - polysaccharides (pectins, sodium alginate, xanthan gum, tara gum, gellan gum, acacia gum and carob gum, ethylcellulose, hydroxypropyl methylcellulose)

The most important determinants of the rheological, thermal, and textural properties of oleogels and thus the quality of oleogel-supplemented products include the type of oil, the content and type of the structuring substance, and the sample preparation parameters. The literature provides numerous data on the use of different types of oils to prepare oleogels (Limpimwong et al., 2017; Alongi et al., 2022; Orhan and Eroglu, 2022; Millao et al., 2023; Thomas et al., 2023; Öğütcü and Yılmaz, 2015a; Öğütcü and Yılmaz, 2015b). It has also been found that the relationship between the structuring substance and the type of oil has an impact on the gelling capacity of the substance used to prepare the oleogel (Li et al., 2021;

Lupi et al., 2017). For example, lower amounts of the gelling agent are necessary when oils with higher content of oleic acid are used. The choice of structuring substances is dependent on their expected effects, gelling strategy, suitability for use in various products, relatively low prices, and commercial availability.

The following methods are used for preparation of oleogels:

– *direct* – the most common method for preparation of oleogels. It consists in dispersion of the structuring substance in liquid oil. Typically, LMOGs are used in this method. Such substances as waxes, fatty acids, monoglycerides, and ethylcellulose are dispersed in the oil phase directly, heated to 65-90°, and then cooled. Cooling the sol results in formation and growth of crystals, which leads to formation of an oleogel structure (Singh et al., 2017; Okuro et al., 2020) (Fig. 1).

Figure 1. Scheme of the direct method for oleogel preparation (authors' scheme)

– *indirect* – involving the use of a polymer for vegetable oil gelling to form a structure in an aqueous solvent or aqueous emulsion, which requires thorough removal of the aqueous solvent to preserve the gel network (Banaś and Hrasym 2021; Patel et al. 2014b; Davidovich-Pinhas 2019). It comprises two procedures:
  - formation of structural emulsions (Fig. 2)

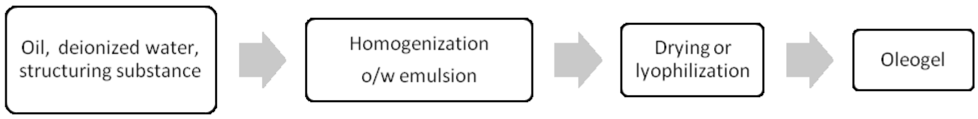

Figure 2. Scheme of the formation of oleogels with the use of emulsion (authors' scheme)

  - formation of liquid oil-saturated foams (Fig. 3)

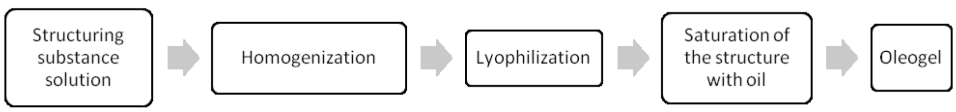

Figure 3. Scheme of the formation of oleogels with the use of foams (authors' scheme)

For example, using tea polyphenol palmitate at a concentration of 2.5% (w/v) mixed with citrus pectin at a concentration of 1.5-4.5% (w/v), stable oleogels based on camellia oil were produced with the emulsion method (Luo et al., 2019). Due to their high content of polyphenols, these oleogels were characterized by higher oxidative stability than the control oil. Bascuas et al. (2020) obtained oleogels from olive oil and sunflower oil with the use of hydroxymethylcellulose and xanthan gum as structuring substances and conventional and vacuum drying techniques. No flaxseed oil-based oleogel was obtained with the use of the vacuum drying method.

In order to improve the properties and stability of oleogels, two- and three-component systems are used to prepare colloidal complexes (Chen et al., 2017; Tavernier et al., 2017). For instance, oleogels prepared from natural waxes usually have a higher melting point than conventional solid fats, which may produce an undesirable waxy aftertaste. Qiu et al. (2018) used nanocomplexes of gelatin, tannic acid, and linseed gum to produce oleogels with the emulsion method. Tannic acid, which is a derivative of polyphenols, is a natural antioxidant, has a large number of hydroxyl groups, and interacts with the carbonyl groups of polysaccharides and proteins in strong covalent and non-covalent interactions. With its ability to scavenge free radicals, tannic acid serves antioxidant functions and prevents the process of oxidation of unsaturated fatty acids in oleogels. Complexation of tannic acid allows its accumulation on the surface of oil droplets to act as a natural cross-linking agent improving the antioxidant activity of emulsions. Additionally, the use of linseed gum (an anionic polysaccharide derived from flax seeds) characterized by excellent thickening and emulsifying properties accompanied by good gelling properties ensures a more stable oleogel structure with important health benefits.

Oleogels - application and examples of solutions in selected food products

Various applications can be proposed taking into account the different properties and functional features of structured oil systems. Oleogels have been used in many food products, e.g. in spreads and in bakery, confectionery, and dairy products, not only to replace *trans* and saturated fats but also to use other important functions of oleogels, i.e. carrying water-insoluble bioactive substances, stabilizing products without emulsifiers, binding oils, and imparting heat resistance to products (Pușcaș et al., 2020). Examples of the use of oleogels in confectionery products are listed in Table 3.

The fat phase has the greatest impact on the quality of chocolate, fillings, or confectionery products. Cocoa butter used in the production of chocolate is responsible for its hardness, ability to temper, and melting point. A chocolate product may contain on average up to 20% saturated fat. Hence, it is highly desirable to reduce the saturated fat content of chocolate through the use of oleogels. Espert et al. (2021) investigated the suitability of oleogel produced with the emulsion method and sunflower oil and HPMC (hydroxypropylcellulose) to be applied as a partial substitute of cocoa butter CB (50/50 replacement) in a chocolate recipe in order to design a confectionery product with reduced content of saturated fats. The composition of the starting oil-in-water emulsions was 47% (w/w) of high oleic sunflower oil. The partial replacement of cocoa butter with the oleogel significantly reduced the hardness of the chocolate, whereas its higher dose increased this parameter. Ultimately, the results indicated that HPMC and sunflower oil oleogels are a suitable alternative for reduction of the CB content in chocolate.

Table 3.
Examples of application of oleogels in confectionery products and the structuring method

Oleogels	Structuring method and effects of application		
Pomegranate seed oil gelled with 5% of saturated monoglycerides, beeswax, and propolis	Direct dispersion method	50% replacement of palm oil with oleogels in chocolate spreads	Fayaz et al. (2017)
Corn oil structured with 10% of monoglyceric stearate, 10% of β-sitosterol (8:2) or 10% of ethylcellulose	Direct dispersion method	Corn oil-based oleogel with monoglyceric stearate replacing 100% of cocoa butter in dark chocolate. Soft texture and low solid fat content	Li and Liu (2019)
Rapeseed oil gelled with 2% of shellac wax	Direct dispersion method	The oleogel exerted an oil-binding effect; 27% of palm oil was replaced with the oleogel in chocolate spreads.	Patel et al. (2014a)
Olive oil and sunflower oil structured with HPMC and xanthan gum	Indirect method	Replacement of coconut butter with oleogels at the ratio of 50/50 and 100/0. The 50% coconut butter replacement yielded a structure in chocolate spreads similar to the control.	Bascuas et al. (2020)
Sunflower oil gelled with 10% or 25% of a 1:1 mixture of γ-oryzanol and β-sitosterol	Direct dispersion method. Storage at ambient temperature	2.5% or 14% sunflower oil-based oleogels were incorporated into the praline composition in different layers; oil migration was reduced by 50%.	Wendt et al. (2017)
Soybean oil gelled with 1%, 3%, and 6% of monoglycerides and with 6%, 8%, and 10% of a mixture (1:1) of sorbitan tristearate and lecithin	Direct dispersion method;crystallization at ambient temperature in the case of monoglyceride oleogels and at 5°C for 24 h in the case of sorbitan tristearate and lecithin oleogels	3% and 6% of soy monoglyceride oleogels and 8% and 10% of sorbitan tristearate and lecithin oleogels exhibited similar properties to those of fats present in praline filling	Si et al. (2016)
Rice bran oil structured with 1.5%, 2.5%, 3.0%, and 3.5% of beeswax for replacement of 17%, 33%, and 50% of palm oil in nut fillings	Direct dispersion method	Replacement of 17% of palm oil with oleogel in nut fillings; evident oil-binding properties	Doan et al. (2016)
Rapeseed oil structured with 10% of carnauba wax	Direct dispersion method	25-50% replacement of fat in cakes	Kim et al. (2017)

Oleogels	Structuring method and effects of application		
Sunflower seed oil structured with 10% of beeswax and mixed with 20%, 40%, 70%, and 85% of fat	Direct dispersion method	45%, 30%, and 15% replacement of fat in gluten-free cakes	Demirkesen and Mert (2019)
Sunflower wax, shellac wax, and beeswax added to halva in the dose of 1%, 3%, and 5%	Tahini and sugar syrup were prepared in isothermal conditions and the waxes were dispersed in the mixture	100% replacement of hydrogenated palm stearin, which is used as an additive in halva production	Öğütcü et al. (2017)
High oleic sunflower oil (HOSO), rice bran wax (RBW), and polysorbate 80	Direct dispersion method (temperature of the mixture: 80°C)	10% of rice bran wax oleogel (RBW); a mixture consisting of 90% of high oleic sunflower oil (HOSO) and 10% of RBW was used to replace solid fats in ice cream	Zulim Botega. et al. (2013a)

With the aim of development of functional chocolate, corn oil was used as the base oil, and β-sitosterol was combined with oryzanol/stearic acid/lecithin to produce respective oleogels (GO, SO, and LO). Among the three oleogels, the formulation with β-sitosterol and γ-oryzanol had a hard texture, the highest oil-binding capacity, and the best thermal resistance; hence, it can replace half of the cocoa butter in chocolate and impart properties similar to those of dark chocolate (Sun et al., 2021). In a study conducted by Bascuas et al. (2021), chocolate spreads were designed with the use of oleogels containing two oils (olive and sunflower), hydroxypropyl methylcellulose (HPMC), and xanthan gum (XG) as structuring substances. In this way, the lipid profile of the spreads was improved through full or partial replacement of coconut butter used in the preparation thereof.

As reported by Tanti et al. (2016), it is possible to replace fat partially (50% and 75%) in sandwich biscuit creams with rapeseed oil structured with hydroxypropyl methylcellulose (HPMC) and methylcellulose (MC). The oleogels were prepared with the use of the indirect (foam) method and the lyophilization process. The creams were characterized by reduced content of saturated fats, longer oil stability, a less viscous texture, and rheological characteristics similar to those of commercial products. New methods for reduction of the use of saturated fat in a product with functionality similar to that of margarine were investigated by Giacomozzi et al. (2018). To this end, they prepared oleogels from high oleic sunflower oil and saturated monoglycerides and assessed their potential application as a semi-solid fat ingredient in production of muffins. The oleogel-containing muffins had better quality than those made using commercial margarine and additionally exhibited a healthier nutritional profile. Onacik-Gür and Żbikowska (2020) used high oleic (HO) rapeseed oil as oleogel structured by various waxes (candelilla, rice bran, yellow and white beeswax), monoacylglycerols, and ethylcellulose for preparation of short-dough biscuits. Although the oleogels differed significantly from palm oil in terms of texture and viscosity, the use of the oleogel with 5% of monoacylglycerols as baking fat yielded biscuits with properties similar to those of the control sample (containing palm oil). Pehlivanoglu et al. (2018) assessed the application of unsaturated fatty acid-rich and low-calorie oleogels as fat substitutes in cakes. The oleogels were prepared using 5% of carnauba wax (to the oil phase), palm oil, high oleic (HO) sunflower oil, and fat produced in the "in-Es" technology: 30% of palm oil, 25% of cottonseed oil, 25% of palm kernels, 20% of palm stearin). The textural and rheological properties of the biscuits as well as their qualitative traits were comparable to those of control biscuits. This indicates that it is possible to produce unsaturated fatty acid-rich biscuits with a lower calorific value.

Oleogels are a promising substitute for saturated fats also in the production of ice cream (Zulim Botega et al., 2013b; Moriano and Alamprese, 2017; Nazarewicz et al., 2022). The use of sunflower oil oleogels with the addition of phytosterols and γ-oryzanol as a substitute for milk cream yielded ice cream with qualitative characteristics comparable to those of artisanal ice cream products. Similarly, Silva-Avellaneda et al. (2021) reported a possibility of production of ice cream with the use of oleogels from whey and high oleic palm oil as a substitute of cream without considerable differences in viscosity and texture properties, e.g. hardness and elasticity. However, the oleogel was obtained in the microfluidization process (high-pressure method), which yields structural systems (more stable emulsions) without additional thermal treatments. The concentration and type of oil are very important factors in this method, as the establishment of the maximum amount of hydrophobic components in the emulsion can prevent formation of crystals.

Conclusions

Recent changes and trends associated with the elimination of *trans* fatty acids from food products, the growing consumer awareness of their negative impact on the organism, and the environmental considerations related to sustainable practices in palm oil production have initiated numerous studies on fat substitutes. Oleogels appear to be promising fat substitutes in bakery and breakfast products, margarines, chocolates, and chocolate-based products. Despite the promising results of the formulas developed in the analyzed studies, the wide range of oleogelation techniques, the availability of structuring substances, the similarities between the physical properties of oleogels and fat-containing food products, the nutritional values provided by vegetable oils, and the positive results of sensory analysis and hedonic tests of oleogel-containing products, there are still many challenges and technological problems preventing the commercial use of oleogels in the industry.

Taking into account technological issues, the limitations of application of oleogels in industry may be associated with the need for identification of structuring substances that can convert vegetable oils into oleogels at low concentrations and can be directly used as food ingredients. It is also important to develop oleogels with higher physical and antioxidant stability and potential to be used in a wide range of foods in various production conditions and give desired sensory properties to the final product. Another issue to consider for commercial use of oleogels is the lack of evidence on the safety and health benefits for the consumer. In most cases, the health benefits of oleogels are associated with the high content of unsaturated fatty acids compared to the content of saturated fats. However, insufficient research has been done to investigate the safety and potential health benefits of some oleogels or oleogelators in human, animal, or cell models. Furthermore, there may be a variety of interactions between oleogels and food ingredients processed in certain conditions, e.g. at high temperatures. Therefore, the safety and bioavailability of ingredients contained in products modified with oleogels should be verified. Profitability is another issue. Consumers' food choices and purchasing behavior are significantly influenced by the price of food products. Therefore, finding effective and cheap structuring substances is highly important for promotion of the use of oleogels in the food industry. Although many types of oleogelators have been identified and used in the preparation of oleogels, the information on their availability and cost is limited. Some gelling agents, e.g. ethylcellulose, have been suggested as inexpensive and natural oleogelators to be used for large-scale oleogel production. Considering its nutritional and environmental values, the oleogelation technique has great potential for future industrial applications.

References

Alongi, M., Lucci, P., Clodoveo, M.L., Schena, F.P., & Calligaris, S. (2022). Oleogelation of extra virgin olive oil by different oleogelators affects the physical properties and the stability of bioactive compounds. *Food Chemistry, 368,* 130779,

Banaś, K., & Harasym, J. (2021). Natural gums as oleogelators. *International Journal of Molecular Sciences, 22*, 12977.

Bascuas, S., Espert, M., Llorca, E., Quiles, A., Salvador, A., & Hernando, I. (2021). Structural and sensory studies on chocolate spreads with hydrocolloid-based oleogels as a fat alternative. *LWT - Food Science and Technology, 135*, 110228,

Bascuas, S., Hernando, I., Moraga, G., & Quiles, A. (2020). Structure and stability of edible oleogels prepared with different unsaturated oils and hydrocolloids. *International Journal of Food Science & Technology, 55,* 1458-1467.

Chen, X.W., Wang, J.M., Guo, J., Wan, Z.L., Yin, S.W., & Yang, X.Q. (2017). Hierarchical high internal phase emulsions and transparent oleogels stabilized by quillaja saponin-coated nanodroplets for color performance. *Food Function, 8,* 823-831.

Davidovich-Pinhas, M. (2019). Oil structuring using polysaccharides. *Current Opinion in Food Science, 27*, 29-35.

Demirkesen, I., & Mert, B. (2019). Utilization of beeswax oleogel-shortening mixtures in gluten-free bakery products. *Journal of the American Oil Chemists' Society, 96,* 545-554.

Doan, C.D., Patel, A.R., Tavernier, I., De Clercq, N., Van Raemdonck, K., Van de Walle, D., Delbaere, C., & Dewettinck, K. (2016). The feasibility of wax-based oleogel as a potential co-structurant with palm oil in low-saturated fat confectionery fillings. *European journal of lipid science and technology, 118,* 1903-1914.

Espert, M., Hernández, M.J., Sanz, T., & Salvador, A. (2021). Reduction of saturated fat in chocolate by using sunflower oil-hydroxypropyl methylcellulose based oleogels. *Food Hydrocolloids, 120*, 106917.

Fayaz, G., Goli, S.A.H., Kadivar, M., Valoppi, F., Barba, L., Calligaris, S., & Nicoli, M.C. (2017). Potential application of pomegranate seed oil oleogels based on monoglycerides, beeswax and propolis wax as partial substitutes of palm oil in functional chocolate spread. *LWT - Food Science and Technology, 86,* 523-529.

FDA Food and Drug Administration. (2015). Final determination regarding partially hydrogenated oils (removing trans-fat). *Retrieved 20*(01), 2019,

Giacomozzi, A.S., Carrín, M.E., & Palla, C.A. (2018). Muffins elaborated with optimized monoglycerides oleogels: From solid fat replacer obtention to product quality evaluation. *Journal of Food Science, 83*(6), 1505-1515.

Gutiérrez-Luna, K., Astiasarán, I., & Ansorena, D. (2022). Gels as fat replacers in bakery products: A review. *Critical Reviews in Food Science and Nutrition, 62*(14), 3768-3781.

Kim, J.Y., Lim, J., Lee, J., Hwang, H.S., & Lee, S. (2017). Utilization of oleogels as a replacement for solid fat in aerated baked goods: Physicochemical, rheological, and tomographic characterization. *Journal of Food Science, 82,* 445-452.

Krajewska, M., Ślaska-Grzywna, B., & Andrejko, D. (2016). Physical properties of seed of the selected oil plants. *Agricultural Engineering, 20*(1), 69-77.

Li, L., & Liu, G. (2019). Corn oil-based oleogels with dierent gelation mechanisms as novel cocoa butter alternatives in dark chocolate. *Journal of Food Engineering, 263,* 114-122.

Li, S., Wu, G., Li, X., Jin, Q., Wang, X., & Zhang, H. (2021). Roles of gelator type and gelation technology on texture and sensory properties of cookies prepared with oleogels. *Food Chemistry, 356*, 129667.

Limpimwong, W., Kumrungsee, T., Kato, N., Yanaka, N., & Thongngam, M. (2017). Rice bran wax oleogel: A potential margarine replacement and its digestibility effect in rats fed a high-fat diet. *Journal of Functional Foods, 39*, 250-256.

Luo, S.Z., Hu, X.F., Jia, Y.J., Pan, L.H., Zheng, Z., Zhao, Y.Y., Mu, D.D., Zhong, X.Y., & Jiang, S.T. (2019). Camellia oil-based oleogels structuring with tea polyphenol-palmitate particles and citrus pectin by emulsion-templated method: Preparation, characterization and potential application. *Food Hydrocolloids, 95,* 76-87.

Lupi, F.R., Shakeel, A., Greco, V., Baldino, N., Calabrò, V., & Gabriele, D. (2017). Organogelation of extra virgin olive oil with fatty alcohols, glyceryl stearate and their mixture. *LWT - Food Science and Technology, 77,* 422-429.

Millao, S., Iturra, N., Contardo, I., Morales, E., Quilaqueo, M., & Rubilar, M. (2023). Structuring of oils with high PUFA content: Evaluation of the formulation conditions on the oxidative stability and structural properties of ethylcellulose oleogels. *Food Chemistry, 405*, 134772.

Moriano, M.E., & Alamprese, C. (2017). Organogels as novel ingredients for low saturated fat ice creams. *LWT - Food Science and Technology, 86,* 371-376.

Nazarewicz, S., Kozłowicz, K., Kobus, Z., Gładyszewska, B., Matwijczuk, A., Ślusarczyk, L., Skrzypek, T., Sujka, M., & Kozłowicz, N. (2022). The use of ultrasound in shaping the properties of ice cream with oleogel based on oil extracted from tomato seeds. *Applied Sciences, 12*(18), 9165.

Nishida, C., & Uauy, R., Kumanyika, S. Shetty, P. (2004). The Joint WHO/FAO Expert Consultation on diet, nutrition, and the prevention of chronic diseases: process, product, and policy implications. *Public Health Nutrition, 7*, 245-250.

Öğütcü M., & Yılmaz E. (2015b). Characterization of hazelnut oil oleogels prepared with sunflower and carnauba waxes. *International Journal of Food Properties, 18,8,* 1741-1755.

Öğütcü, M., & Yılmaz, E. (2015a). Comparison of the pomegranate seed oil organogels of carnauba wax and monoglyceride. *Journal of Applied Polymer Science, 132,* 41343.

Öğütcü, M., Arifoglu, N., & Yılmaz, E. (2017). Restriction of oil migration in tahini halva via organogelation. *European Journal of Lipid Science and Technology, 119*, 1600189.

Okuro, P.K., Martins, A.J., Vicente, A.A., & Cunha R.L. (2020). Perspective on oleogelator mixtures, structure design and behaviour towards digestibility of oleogels. *Current Opinion in Food Science, 35*, 27-35.

Onacik-Gür, S., & Żbikowska, A. (2020). Effect of high-oleic rapeseed oil oleogels on the quality of short-dough biscuits and fat migration. *Journal of Food Science and Technology, 57*(5), 1609-1618.

Orhan, N. O., & Eroglu, Z. (2022). Structural characterization and oxidative stability of black cumin oil oleogels prepared with natural waxes. *Journal of Food Processing and Preservation*, *00*, e17211.

Patel, A.R., Rajarethinem, P.S., Gredowska, A., Turhan, O., Lesaer, A., De Vos, W.H., Van de Walle, D., & Dewettinck, K. (2014a). Edible applications of shellac oleogels: spreads, chocolate paste and cakes. *Food Function, 5,* 645-652.

Patel, A.R., Cludts, N., Sintang, M.D., Lewille, B., Lesaffer, A., & Dewettinck, K. (2014b). Polysaccharide-based oleogels repared with an emulsion-templated approach. *ChemPhysChem, 15*, 3435-3439.

Pehlivanoglu, H., Ozulku, G., Yildirim, R.M., Demirci, M., Toker, O.S., & Sagdic, O. (2018). Investigating the usage of unsaturated fatty acid-rich and low-calorie oleogels as a shortening mimetics in cake. *Journal of Food Processing and Preservation, 42*, e13621.
Puşcaş, A., Mures V., Socaciu C., & Muste S. (2020). Oleogels in Food: A Review of Current and Potential Applications. *Foods, 9,* 70.
Qiu, C., Huang, Y., Li, A., Ma, D., & Wang, Y. (2018). Fabrication and characterization of oleogel stabilized by gelatin-polyphenol polysaccharides nanocomplexes. *Journal of Agricultural and Food Chemistry, 66,* 13243-13252.
Si, H., Cheong, L.-Z., Huang, J. Wang, X., & Zhang, H. (2016). Physical properties of soybean oleogels and oil migration evaluation in model praline system. *Journal of the American Oil Chemists' Society, 93,* 1075-1084.
Silva-Avellaneda, E., Bauer-Estrada, K., Prieto-Correa, R.E., & Quintanilla-Carvajalm, M.X. (2021). The effect of composition, microfluidization and process parameters on formation of oleogels for ice cream applications. *Scientific Reports, 11*, 7161.
Singh, A., Auzanneau, F.I., & Rogers, M.A. (2017). Advances in edible oleogel technologies - A decade in review. *Food Research International, 97*, 307-317.
Sun, P., Xia, B., Ni, Z.J., Wang, Y., Elam, E., Thakur, K., Ma, Y., & Wei, Z.J. (2021). Characterization of functional chocolate formulated using oleogels derived from β-sitosterol with γ-oryzanol/lecithin/stearic acid. *Food Chemistry, 360,* 130017.
Tanti, R., Barbut, S., & Marangoni, A.G. (2016). Hydroxypropylmethylcellulose and methylcellulose structured oil as a replacement for shortening in sandwich cookie creams. *Food Hydrocolloid*, *61,* 329-337.
Tavernier, I., Patel, A.R., Van der Meeren, P., & Dewettinck, K. (2017). Emulsiontemplated liquid oil structuring with soy protein and soy protein: k-carrageenan complexes. *Food Hydrocolloids, 65*,107-120
Thomas, P.E., Saravanan, M., & Prabhasankar, P. (2023). Virgin coconut oil oleogel: gelation mechanism, rheological, structural and thermal properties. *International Journal of Food Science & Technology, 58,* 1434-1443.
Wendt, A., Abraham, K., Wernecke, C., Pfefier, J., & Flöter, E. (2017). Application of β-sitosterol + γ-oryzanol-structured organogel as migration barrier in filled chocolate products. *Journal of the American Oil Chemists' Society, 94,* 1131-1140.
WHO, World Health Organization. (2019). *Healthy Diet*. Available online: https://www.who.int/newsroom/fact-sheets/detail/healthy-diet (accessed on 11 October 2019).
Zulim Botega, D.C., Marangoni, A.G., Smith, A.K., Goff, H.D. (2013a). The potential application of rice bran wax oleogel to replace solid fat and enhance unsaturated fat content in ice cream. *Journal of Food Science, 78*(9), C1334-9.
Zulim Botega, D.C., Marangoni, A.G., Smith, A.K., Go, H.D. (2013b). Development of formulations and processes to incorporate wax oleogels in ice cream. *Journal of Food Science, 78,* C1845-C1851.

ZASTOSOWANIE STRUKTURYZOWANYCH OLEJÓW ROŚLINNYCH W WYBRANYCH PRODUKTACH SPOŻYWCZYCH

Streszczenie. Wspólne zalecenia ustawowe opracowane przez Organizację Narodów Zjednoczonych do spraw Wyżywienia i Rolnictwa (FAO) i Światową Organizację Zdrowia (WHO), większa świadomość konsumenta, względy środowiskowe potwierdzają konieczność ograniczenia spożycia nasyconych kwasów tłuszczowych w diecie człowieka. Doprowadziło to do opracowania innowacyjnych metod zastępowania nasyconych tłuszczów w produktach spożywczych. Taką alternatywą są oleożele otrzymywane różnymi metodami. Stąd w pracy dokonano analizy aktualnych zastosowań oleożeli na wybranych produktach spożywczych wraz z mechanizmami ich powstawania. Na podstawie dokonanej analizy badań prowadzonych przez wielu autorów, oleożele (oleje strukturyzowane) mogą zastąpić tłuszcze trans i nasycone w produktach spożywczych i mieć zastosowanie w rozwoju takich jak produkty do smarowania, pieczywo, słodycze czy nabiał. Jednak nadal istnieje wiele wyzwań oraz problemów technologicznych, które uniemożliwiają komercyjne zastosowanie opracowanych oleożeli w przemyśle. Ważne jest także opracowanie oleożeli o wyższej stabilności fizycznej i antyoksydacyjnej, które mogą być stosowane w szerokim zakresie żywności w różnych warunkach produkcyjnych i nadać produktom końcowym pożądane właściwości sensoryczne. Oleożelifikacja daje jednak duży potencjał do zastosowania przemysłowego w przyszłości ze względu na wartości żywieniowe i środowiskowe.

Słowa kluczowe: oleje roślinne, substancje strukturotwórcze, oleożele